BENEFITS OF WARRANTIES TO INDIANA

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Submitted July 2003
Revised October 2003

Submitted for consideration of presentation and publication at the

2004 Annual Meeting of the Transportation Research Board

TRB Committees A2D03, A2D05, A3C05

Word Count	
Abstract	244
Tables (5 @250 ea.)	1,250
Figures (9 @250 ea.)	2,250
Text	3,843
TOTAL Words	7,587

ABSTRACT

Several states have experimented using performance warranties on hot-mix asphalt pavements. Generally, the quality of warranted HMA is perceived to be better. Also, it is believed that pavement life will be extended.

Various methods can be used to define the benefits of warranties. Benefits have to be related to the performance life of the pavement and the cost. This paper documents the effectiveness of the Indiana 5-year performance warranties. The paper demonstrates that projected life of the warranted HMA pavements are being extended an additional 9 years when evaluating IRI and rutting criteria over the typical design life of the pavements.

The cost effectiveness of the warranted pavements, even though the initial costs are 5-10 percent higher, are significant when considering the extended life of the warranted pavements. Overall cost to maintain the network Interstate smoothness at a constant 2002 value is $1.08 Billion dollars using warranties, and $1.47 Billion dollars for non-warranty projects or a savings for warranty projects of 27 percent. Warranty projects require fewer demands on budgets and provide for lower network IRI at the same effective age of the pavements.

Indiana HMA warranties have accomplished the initial goals of both the Indiana DOT and HMA Industry by providing smoother and safer pavements with fewer defects over a longer period of time, which reduces delays and congestion. At the same time the economic benefits of warranted pavements are significant.

Key Words: Hot Mix Asphalt, HMA, Warranties, Performance, IRI, Rutting, QC/QA

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INTRODUCTION

Like most States, the Indiana DOT has examined innovative ways to improve or manage construction activities and material production for many years. Like many States, the DOT felt that if they were in control of the whole process, the resulting work would produce long lasting pavements. However, the Indiana DOT found that "method-type" specifications did not always a guarantee good performance product.

In the mid 1980's, to improve the probability of good performance, the DOT statistically evaluated over one hundred Hot Mix Asphalt (HMA) projects to develop a Quality Control/Quality Assurance (QC/QA) program specification. These QC/QA specifications, implemented in 1986, empowered the Contractor with additional responsibilities in mixture design, and plant and field operations that raised the overall quality of HMA projects. A requirement for Contractor Quality Control Plans was introduced and has been refined over the years to reflect changes in the program, product, and operations.

In the interest of improving pavement performance and speed of delivery, various States began using some innovative contracting procedures in the early 1990’s. Such innovations included; incentive/disincentive, cost-plus-time, lane-rental, warranties, and design-build. The Indiana DOT became more interested in the process as a result of a Transportation Research Board (TRB) program on warranties in 1994.

Before 1991, the Federal Highway Administration (FHWA) restricted the use of warranties because of a prohibition of the use of Federal funds for routine maintenance. Warranties were considered by some to be an extension of maintenance operations. On an experimental basis, the 1991 Intermodal Surface Transportation Efficiency Act permitted warranty projects using Federal-Aid funds. Warranty projects were advanced nationwide through the FHWA Special Experimental Program (SEP #14- Innovative Contracting) on new or rehabilitation construction projects.

In 1994, the Indiana DOT began developing a warranty specification that used QC/QA, cost-plus-time, and lane-rental concepts. In 1996[1] Indiana let their initial warranty project on I-70, east of Indianapolis, as part of the FHWA SEP #14 program.

The improvements in quality implemented by the DOT over the years has been methodical, with each successive step carefully taken to produce longer lasting pavements. Warranties are considered an additional step forward in quality. The DOT's improvements in quality over the last two-decade consists of:

- 1986- QC/QA for Marshal Mixtures Introduced
- 1990- Sampling from the Roadway- Plate Samples
- 1994- Initial Superpave Mixture Implementation
- 1994- QC/QA for Aggregates
- 1995- Quality Control Plans for HMA
- 1996- QC/QA for Binders
- 1996- Warranties for HMA
- 1997- Certified HMA Plants
- 1997- Full SuperPave Mixture Implementation
- 1999- Initial Volumetric Acceptance Introduced
- 2003- Certified HMA Mixtures
- 2003- Full Volumetric Acceptance

Projects constructed using warranty specifications have performed well, better than similar non-warranty projects. Yet, the benefits and cost-effectiveness of warranty projects remain unknown. This paper contains the results of a study to measure the performance and life of warranty pavements and the economic benefit of increased life.

BACKGROUND

In 1995, the National Quality Initiative (NQI) Steering Committee (now the National Partnership for Highway Quality- NPHQ) conducted a National User Survey[2] and reported that the public priorities for highway improvements were; 1) Pavement Conditions (smoother ride and quieter pavements), 2) Safety, and 3) Traffic Flow (reduced delay and congestion). The information gathered from the survey has been used by governmental agencies nationwide as a baseline for direction in targeting improvement programs and initiatives.

When developing a warranty specification the Indiana DOT targeted Interstate routes and selected warranty criteria that emphasize the NPHQ survey results. In addition, the DOT wanted the properties to be measured objectively using current technology. As a result, the warranty criteria are based on properties routinely collected for its Pavement Management System (PMS).

The development of the project criteria used for the warranties was aligned with the PMS to make the project evaluations as objective as possible. The PMS system evaluates all the Interstate routes in the State yearly and the rest of the network bi-annually, therefore the PMS was selected to do the project criteria evaluations for the duration of the warranty periods.

For project warranty criteria the Indiana DOT selected smoothness, rutting, cracking, and friction to best represent the NPHQ priorities and the condition of the pavements. Other engineering defects such as segregation, block cracking, flushing, potholes, etc., were not selected as specific criteria because measurement is subjective. These defects are included indirectly because of their affect to the selected criteria.

When setting up the specification, the DOT desired to measure the entire pavement length rather than sampling only part of it. As a result smoothness, rutting and longitudinal cracking (primarily longitudinal joints) are measured continuously. Friction is tested once each 1.6 kilometers (1.0 miles).

When choosing a length for evaluation sections, there are some practical minimum and maximum values. If evaluation sections are too long, a localized area of poor performance can be diluted and not be detected in the results. If the sections are too short, data processing becomes impractical. The DOT chose a section length to be 100 m (330 ft).

Warranty criteria were selected from an analysis of good-performing five-year old pavements evaluated using the 100 m (330 ft) section lengths. From this evaluation a distribution of performance was determined and warranty thresholds were set at the mean plus two standard deviations.

The Indiana PMS data collection system consists of a continuous high-speed video-logging system that uses laser sensors to measure longitudinal and transverse profiles for all pavement surface types. The longitudinal profile is used to calculate the International Roughness Index (IRI). At the same time, a rut bar containing five sensors measures a transverse profile every 150 mm (6 in.) along the road. Rut depth is calculated from the transverse profile. An average IRI and rut depth is then calculated for each 0.16 km (0.1 mi.) length of road measured. The video log is used to evaluate cracking and other selected distresses of a section 0.16 km (0.1 mi.) long in each 1.6 km (1.0 mi.) of roadway. A total Pavement Condition Rating[3] (PCR) is determined for all the sections and reported on an annual basis.

Friction is tested by the DOT Division of Research yearly on all the Interstate routes and the rest of the network tri-annually. A smooth-tire, locked-wheel skid tester is used and tests are completed in each 1.6 km (1.0 mi.) for the entire network and each 100 m (330 ft) on the warranty projects.

A specialized process[4] is used to collect condition data on the warranty projects to ensure the project is within the warranty thresholds. Multiple passes are used in each direction. Bridges, concrete pavement sections, and weigh-in-motion sites are eliminated during the data evaluation process. IRI and average rut depth is calculated for each 100 m (330 ft) section. Surface cracking is visually determined and reported for the initial 100 m (330 ft) in each 1.6 km (1.0 mi.) section.

Performance warranty specifications for HMA pavements require QC/QA programs for HMA production, aggregates, binders, and field operations. The DOT has the responsibility to provide the structural design, and minimum aggregate, binder, and mixture requirements. The Contractor has the responsibility for material selection, mixture design, and production, as well as all sampling and testing requirements during the project construction activities. The DOT is then responsible for project warranty evaluations and reporting throughout the life of the warranty period.

The perceived benefits to the DOT for utilizing HMA warranties include[1]:

- Improved material quality and construction quality.
- Reduced demand for DOT supervision and material testing.
- Accelerated construction without sacrificing workmanship.
- Elimination of early maintenance costs.
- Encouragement for innovation.
- Addressing lobbying efforts by contractors and producers to have greater production flexibility and use of innovative products or procedures.

Following implementation of the HMA Warranty program, the DOT extended the process to Portland Cement Concrete (PCC) pavements and to pavement preservation activities, i.e., Micro-surfacing. The PCC warranty specification was developed similar to the HMA with its' warranty criteria also related to NPHQ and performance of the pavement. The Micro-surfacing warranty is a two-year materials and workmanship type warranty. The DOT has also established warranty programs for erosion control and for bridge painting activities. Neither of these type projects is included in this paper.

The Indiana DOT has not implemented warranty projects widely, preferring instead to implement the program one step at a time and to evaluate the outcome of the experiences. Selected projects are identified based on many factors, one of which is the risk factors to both the DOT and the Contractors.

Table 1 contains a list of performance warranty projects constructed to date. All the HMA rehabilitation projects are overlays of crack and seated or rubblized PCC pavements, which is the typical Indiana DOT rehabilitation strategy. Three projects, a total of 29.6 km (18.5 miles) are older than the five-year warranty. Another four projects, 62.5 km (39.0 miles), are constructed and remain under warranty. Currently under construction there are 35.4 km (22.2 miles) of HMA pavement and 13.3 km (8.3 miles) of PCC pavement.

Two of the nine projects constructed to date have required remedial action to comply with the warranty friction threshold. The effective pavement was replaced using mill and fill under the terms of the warranty contract. Warranty thresholds for smoothness, rutting and cracking have not been exceeded on any of the projects.

For the purpose of determining the benefits of warranties to the DOT, only those HMA projects that have completed their warranty periods or have at least two years of warranty evaluations completed will be used. The PCC and Micro-Surfacing warranty projects, are either under construction at this time or do not have applicable data to evaluate.

ANALYSIS

The Indiana DOT perceived that warranted pavements were performing better than typical non-warranted pavements, but the difference had not been quantified. The objective of this study is to:

1. Quantify the improved performance of warranted HMA pavements.
2. Estimate their expected life, and
3. Calculate cost savings of the longer life.

Pavement condition data[3] for IRI and rutting on the entire Indiana Interstate network was used. The data from the PMS was collected in 2002 and was summarized in 0.16 km (0.1 mi.) sections as per normal DOT practices. Unlike specially processed warranty data, this data set included bridges, concrete bridge approach slabs, and other short pieces of PCC pavement within an HMA project. The 2002 data set was sorted to remove PCC and non-interstate projects. What remained was 1430 kilometers (890 miles) of pavement reported in 0.16 km (0.1 mi.) pieces.

Performance data for both IRI and rutting is reported in both directions. The database also includes various contract specific information such as the dates of construction and acceptance, construction costs, specialty information (i.e. mixture type Superpave vs. Marshall), and the names of the contractor for each section, etc.

The following analyses were conducted:

1. A histogram of rutting and IRI was developed for the warranty pavements and non-warranty pavements.
2. Condition deterioration curves were developed for all pavements for IRI and rutting.
3. Warranted pavements were compared to non-warranted pavement performance.
4. Future performance of warranted pavements was estimated.
5. Cost estimates were obtained for warranted pavements compared to non-warranted ones and savings to the DOT were estimated.

PERFORMANCE COMPARISON

A subset of Interstate HMA pavements 4 to 6 years old was selected to compare the performance of warranted and non-warranted pavements. Histograms for IRI and rutting are shown in Figures 1 and 2 respectively. The histograms are normalized to show the percentage of pavements in each condition.

For the warranted pavements, the IRI of most of the sections is in the range of 40 to 50 and 50 to 60 in./mi. For the non-warranty pavements, the largest percentage is in the 50 to 60 in./mi. category. Variability in performance is also evident in Figure 1. The non-warranty pavements have nearly equal percentages in the 40 to 50, 50 to 60, 60 to 70 and 70 to 80 in./mi. ranges. On the other hand, the warranted pavements have a very large percentage in the 40 to 50 and 50 to 60 ranges only. There are very few sections in the 60 to 70 range or higher.

From Figure 1, 93 percent of the warranted pavement sections are smoother than 110 in./mi. By contrast, only 89 percent of the non-warranted sections meet the same criteria. Table 2 lists the statistical values for comparison. Figure 3 shows a roughness comparison between warranted and non-warranted pavements.

A comparison of rutting from Figure 2 shows that over half of the warranted sections have less than 1.5 mm (0.06

in.), whereas, only a third of the non-warranted pavements meet the same criteria.

Also from Figure 2, 96 percent of the warranted pavements have a rut depth of less than 4 mm (0.16 in.), whereas, only 79 percent of the non-warranted pavements meet the same criteria. Figure 4 shows a comparison of rut depth between warranted and non-warranted pavements.

In summary, warranted pavements have less rutting and are smoother than non-warranted pavements. Also, the standard deviation is lower. Hence, the warranted pavements are performing better and are more consistent.

WARRANTED HMA PERFORMANCE PREDICTIONS

This section will look at the expected performance of warranted HMA pavements beyond the current age of the warranty projects. The first step of this analysis is to develop typical deterioration curves for non-warranty HMA pavements.

Deterioration curves were developed using the 2002 condition database for the Interstate highway system. PCC and warranted HMA pavements were removed from the database. The remaining 8253 non-warranted HMA sections, 1320 kilometers (825 miles), were sorted by age. For each year, an average value of IRI and rut depth was calculated. A plot was then made and a correlation was developed.

Then, the deterioration curve was used to predict the year in which each warranty project would reach the same condition as an average 15-year non-warranted HMA pavement.

Looking at smoothness as shown on Figure 5, IRI, the pavements start at about 70 in./mi., and as the pavements approach 30 years, the IRI approaches 160 in./mi. At 15-years the average IRI is 111 in./mi. The results appear reasonable even though the data includes bridges and bridge approaches.

Using the regression curve from Figure 5, the age when each warranted pavement reaches 111 in./mi. is estimated. For each warranted pavement the curve is shifted vertically to intersect a point defined by the age of the warranted pavement and its roughness. The shifted curve then is used to predict when the warranted pavement will reach 111 in./mi., the average roughness of a non-warranty pavement.

This prediction is probably conservative since it assumes that roughness for the warranted pavement will increase at the same rate as the non-warranted pavement.

The predicted ages for each of the projects being evaluated are shown in Table 3. Most of the warranty projects are performing much better than average. The roughness is considerably lower than an average non-warranty pavement. The age at which roughness is expected to equal the performance of a 15-year old non-warranty HMA pavement ranges from 14.5 years to 36.6 years. The average predicted age is 24.0 years.

Rutting as shown on Figure 6, also presents itself in an expected manner with the initial values of less than 2 mm (0.09 in.) at age one, to 4 mm (0.18 in.) at age 15-years, the typical design life of HMA pavements.

Expected age of each warranted HMA project is obtained by vertically shifting the performance curve as was done for IRI. The predicted age for when each pavement is expected to reach the same rut depth as a 15-year old non-warranted project is shown in Table 4. The predicted ages vary from 9.9 years to 33.2 years with the average being 24.0 years.

WARRANTED HMA COST SAVINGS

To maintain and manage a highway network requires capital investments to rehabilitate pavements as they approach the end of their service lives. The previous section showed that warranted HMA pavements outperform non-warranted projects and provide for longer service lives. Longer life should translate into cost savings to maintain a network at a specified level of performance, or should provide an improved level of performance for the same expenditures.

An analysis was done to estimate future costs and IRI for Interstate highways in Indiana as follows:

- The 0.1-mile segments in the 2002 condition database were used as the baseline.

- The 2002 spreadsheet was duplicated multiple times to provide a workbook, each representing one year from 2002 to 2027.
- In each successive year, the IRI was increased using the equation in Figure 5.
- The workbook containing 25-years of predicted data was replicated to produce three copies, one for each of three analyses; 1) do nothing, 2) non-warranty rehabilitation and 3) warranty rehabilitation.
- For the Do Nothing scenario, no further analysis was done.
- For the Non-Warranty and Warranty rehabilitation scenarios, pieces of road were upgraded using a single budget level of $80 million per year (typical budget for Interstate pavements minus bridges).
- For 2003 and each successive year thereafter, the sections were sorted based on IRI and the $80 million budget was used to “upgrade” the roughest sections.
- Pieces of road were upgraded in 0.1-mile lengths. No attempt was made to agglomerate sections into realistic construction contract lengths.
- Roughness of the upgraded pieces was re-set to Year 0 values and future increases in roughness were incremented using the IRI performance curve.
- Only sections that exceeded the 15-year terminal roughness of 111 in./mile were upgraded. If budget availability exceeded the demand for upgrading, the budget was under-spent.

The average cost of providing warranty projects depends upon the scope of the project, contractor’s experiences and capabilities, bonding, material sources, and traffic demands. According to Indiana Contractors[5] a typical cost for warranties is about 5-10 percent over that which would be for the same project without a warranty.

The average condition of the network under the three scenarios is shown in Figure 7. Under the Do-Nothing scenario, the average roughness of the Interstate network increased from 81 in./mi. to 183 in./mi.

Both rehabilitation scenarios show an initial improvement in average roughness as very rough pieces of road are upgraded. Then, for a few years the average roughness is similar for both scenarios. Thereafter, the predicted average roughness in the non-warranty scenario is higher than the warranty scenario as the upgraded sections degrade more quickly in the non-warranty scenario. Starting at about 2008 and onward, there is a significant difference in the network roughness. In 2018 the non-warranty scenario has a roughness of 89 in./mi. compared to 75 in./mi. in the warranty scenario.

In 2019 the average roughness of the non-warranty scenario begins to improve as the original rehabilitated sections now exceed the 15-year life and are again rehabilitated. On the other hand, the warranty pieces that were originally rehabilitated in the early years have not yet deteriorated to the point of needing rehabilitation again.

The budget demands as shown on Figure 8, for the Non-Warranty and Warranty strategies are different. Over the twenty-five year period $1.416 Billion dollars is spent for the Non-Warranty strategy. The Warranty strategy requires $1.077 Billion to be spent, $339 million, or 24 percent less. Therefore, the Warranty strategy provides a network with less roughness at a lower cost.

Another way of evaluating the performance of the network is to calculate the cost of maintaining the IRI at a constant level. Under the Do-Nothing strategy, no funds are invested to improve network performance, and as a result network roughness increases. In both the Warranty and Non-Warranty strategies, funds are invested and the network IRI is improved.

The cost of improving IRI by one in./mi. was estimated for the Warranty and Non-Warranty strategies. A summation was completed of the area between the Do-Nothing curve and the respective Warranty or Non-Warranty strategy curve. An example is shown in Figure 9 for the Warranty strategy.

The total expenditure under each strategy represents the cost to create the improvement in IRI. Table 5 lists the IRI improvement and costs for each strategy. The average cost of improving the IRI one in./mi. is shown in Table 5. Using a Non-Warranty strategy, the average cost to improve IRI one in./mi. is $1.27 Million and for the Warranty strategy it is $0.93 Million.

Then, knowing the cost of improving ride one in./mi., it is possible to calculate the cost of maintaining the network smoothness at the 2002 level. In 2002 the average network IRI is 81 in./mi. The summation of area beneath the Do-Nothing curve and a line drawn at 81 in./mi. is 1164 in./mi. over the 25-year period. Using a Non-Warranty strategy it will cost $1.474 Billion dollars over the 25-year period. For the Warranty strategy, the cost is $1.077 Billion. In other words, using a Warranty strategy the same level of service can be provided for $397 Million less cost, or a savings of 27 percent.

CONCLUSIONS

Performance evaluations of the HMA warranty projects with respect to age gives us a time-based reference, or in other words, a view of the overall health of the system. Warranties provide a tool to extend the performance of the pavements as well as a cost effective strategy. Specific findings are as follows:

1. Warranty HMA has a lower and more consistent IRI than non-warranty HMA. The mean value of the warranty projects is not only significantly lower, but the standard deviation is also significantly lower.

2. Warranted HMA sections have less rutting than non-warranty sections. Also, rut depths are less variable.

3. Performance of the HMA warranty projects exceeds that of the non-warranted projects. Expected performance for smoothness and rutting before exhibiting the same performance of non-warranted pavements is 24.0 years an additional 9.0 years.

4. Using warranted HMA as a pavement construction strategy requires less demand on budget and provides a smoother (lower IRI).

5. Predicted 25-year cost to maintain network smoothness at a constant 2002 value is $1.08 Billion dollars using a warranty strategy, and $1.47 Billion dollars using a non-warranty.

6. Initial capital costs for HMA warranty projects are approximately 10 percent higher than for non-warranty projects.

7. Use of warranties for HMA projects as a pavement preservation strategy can produce a cost savings of 27 percent.

8. Indiana HMA warranties have accomplished the initial goals of both the Indiana DOT and the HMA Industry by providing smoother and safer pavements with fewer defects over a longer period of time, which reduces delays and congestion.

DISCLAIMER

The views and opinions of the authors do not necessarily reflect those of the Federal Highway Administration, Heritage Research Group, or the Indiana Department of Transportation.

REFERENCES

1. Ward, R.W., ***Executive Summary and Final Report***, Special Project #14, DTFH-71-96-TEO14-IN-13, Indiana Department of Transportation, February 2003.

2. NQI Steering Committee by Coopers & Lybrand, LLP, ***National Highway User Survey***, Washington, D.C., May 1996.

3. Flora, W.F., ***2002 Pavement Condition Data***, Indiana Department of Transportation, Unpublished, November 2002.

4. Flora, W.F., ***HMA Warranty Condition Data Collection Manual,*** Indiana Department of Transportation, Unpublished, 2001.

5. Indiana HMA Contractors, ***Personal Discussions,*** Unpublished, July 2003.

LIST OF TABLES AND FIGURES

Table 1. INDOT Performance Warranty Projects

INDOT WARRANTY PROJECT SUMMARY					
Location	**Length Kilometers (Miles)**	**Pavement Type and Treatment**	**Construction Year**	**Completion Date**	**Warranty Status**
I-70, E. of SR-9, Hancock Co., R-22232	7.11 (4.21)	HMA/ Crk. & Seated PCC	1996	7/96	Complete
I-65, N. of US-31, Bartholomew Co., R-22854	7.86 (4.56)	HMA/ Rubblized PCC	1997	8/97	Complete
I-69, N. of SR-8, Dekalb Co., R-22925	14.67 (8.68)	HMA/ Crk. & Seated PCC	1997	8/97	Complete
I-74, E. of SR-9, Shelby Co., R-23390	18.61 (11.01)	HMA/ Crk. & Seated PCC	1998	9/98	4-years
I-65, N. of Lafayette, Tippecanoe & White Co.'s, R-23500	28.63 (16.94)	HMA/ Rubblized PCC	1998	8/99	3-years
I-74, W. of SR-267, Hendricks Co., R-23898	6.69 (3.96)	HMA/ Crk. & Seated PCC	1999	9/99	3-years
I-65, South of White River, Indianapolis, Marion, Co., R-24327	8.57 (5.07)	HMA/ Rubblized PCC	2001	6/02	1-year
I-64, Illinois State Line to W. of SR-165, Posey Co., R-25808	19.13 (11.32)	HMA/ Rubblized PCC	2002-2003		
I-64, E. of SR-165 to w of Owensville Road, Posey & Vanderburgh Co.'s, R-25142	16.31 (9.65)	HMA/ Rubblized PCC	2002-2003		
SR-28 from SR-27 to Ohio State Line, Wayne Co., RS-25883	138.95-151.30	Micro-Surfacing	5/2002	11/02	Warranty still in progress
I-70, 3.8 miles W. I-465 to 0.9 mile W of I-465, MP 69-72, Marion Co., R-26262	3.36 (2.10)	Micro-Surfacing	6/2002	10/02	Warranty cancelled
I-65, I-265 to N. of N. US-60, Clark Co., R-24550	2.5 (1.48)	PCC	2003		
I-69, S. of US-24 to N. of SR-14, Allen Co., R-26484	10.82 (6.40)	PCC	2003		
I-65, N. of 29[t]th, Marion, Co., R-26911	3.30 (2.00)	Micro-Surfacing	2003	2003	

Table 2. Statistical Performance Comparisons

	HMA Warranty Projects	HMA Non-Warranty Projects
International Roughness Index, (in./mile)		
Mean	59	77
Standard Deviation	27	39
Rut Depth, (in.)		
Mean	0.08	0.11
Standard Deviations	0.04	0.08

Table 3: Estimated Smoothness vs. Life of Warranty Pavements

Highway	Age years	IRI in/mi	Ave Non-Warranted HMA IRI, in/mi	Predicted Age at IRI = 111.0
I-70	7	58.5	85.4	26.6
I-65	6	40.7	82.6	36.6
I-69	6	59.6	82.6	24.9
I-74	4	67.6	77.4	19.1
I-65	4	54.5	77.4	25.7
I-74	4	64.8	77.4	20.4
I-65	2	73.7	72.5	14.5
Average				24.0

Table 4: Estimated Rutting vs. Life of Warranty Pavements

Highway	Age years	Rut Depth inches	Ave Non-Warranted HMA Rut, inches	Predicted Age at Rut Depth = 0.18 inches
I-70	7	0.05	0.12	33.2
I-65	6	0.09	0.11	19.5
I-69	6	0.05	0.11	30.6
I-74	4	0.05	0.10	29.8
I-65	4	0.13	0.10	9.9
I-74	4	0.07	0.10	23.5
I-65	2	0.07	0.09	21.3
Average				24.0

Table 5: Cost of Improving IRI

	Total IRI Improvement in./mi.	Total Capital Investment $ Billions	IRI Unit Cost $ Millions
Non-Warranty Strategy	1,118	$1.416	$1.27
Warranty Strategy	1,297	$1.200	$0.93

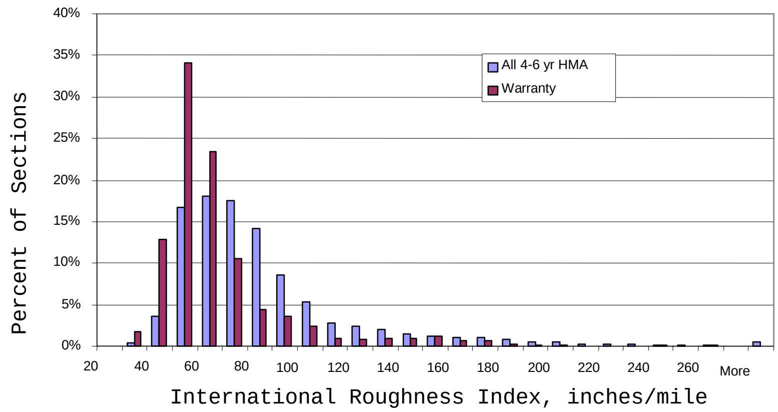

Figure 1: IRI Distribution of HMA Projects

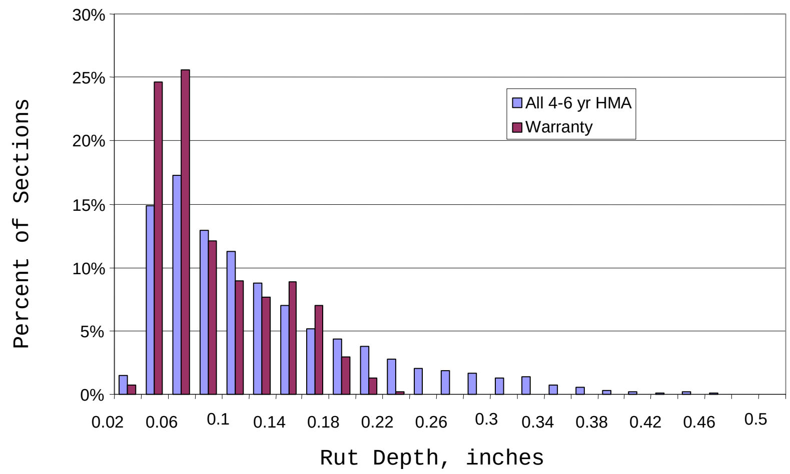

Figure 2: Rutting Distribution of HMA Projects

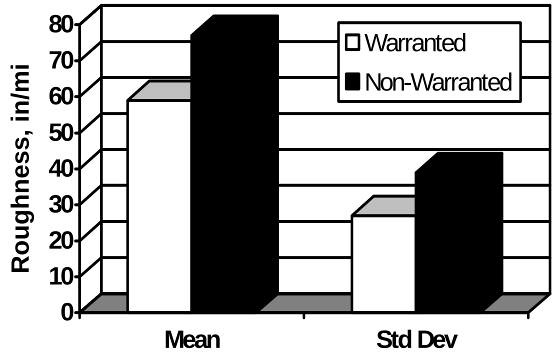

Figure 3: Comparison of Roughness for Warranted and Non-Warranted HMA

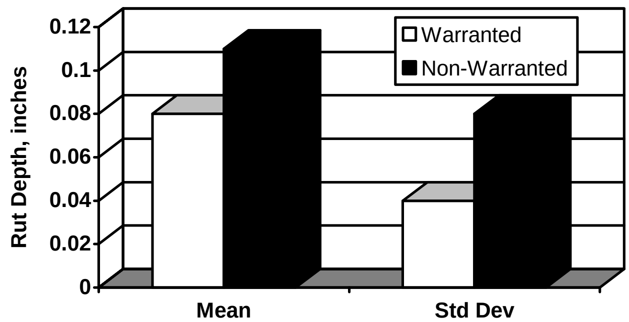

Figure 4: Comparison of Rut Depth for Warranted and Non-Warranted HMA

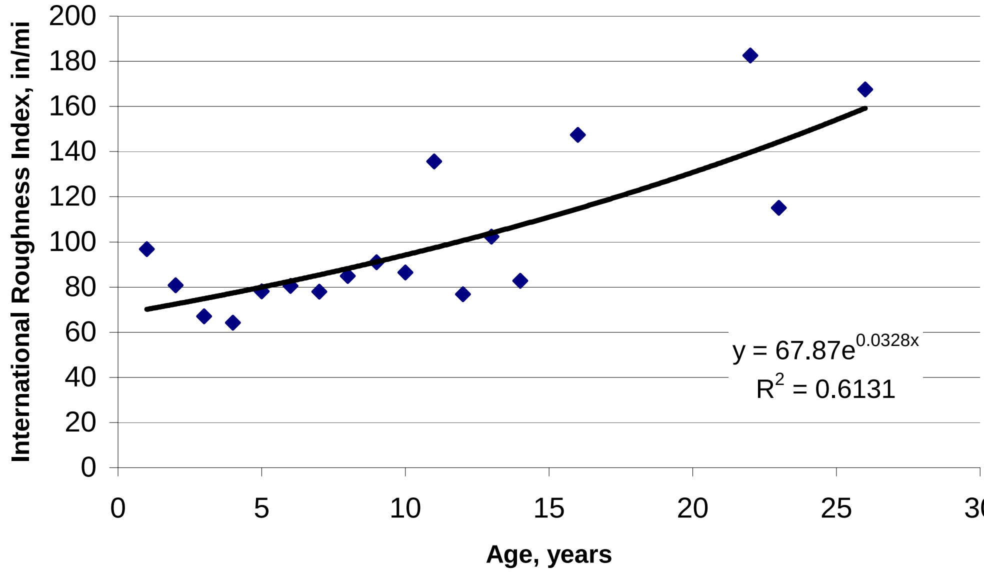

Figure 5: IRI versus Age of Non-Warranted HMA Pavement

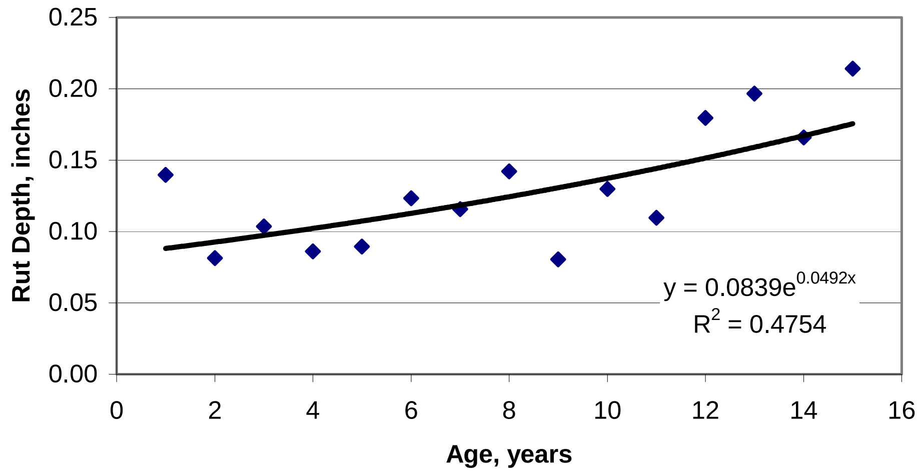

Figure 6: Rutting versus Age of Non-Warranted HMA Pavement

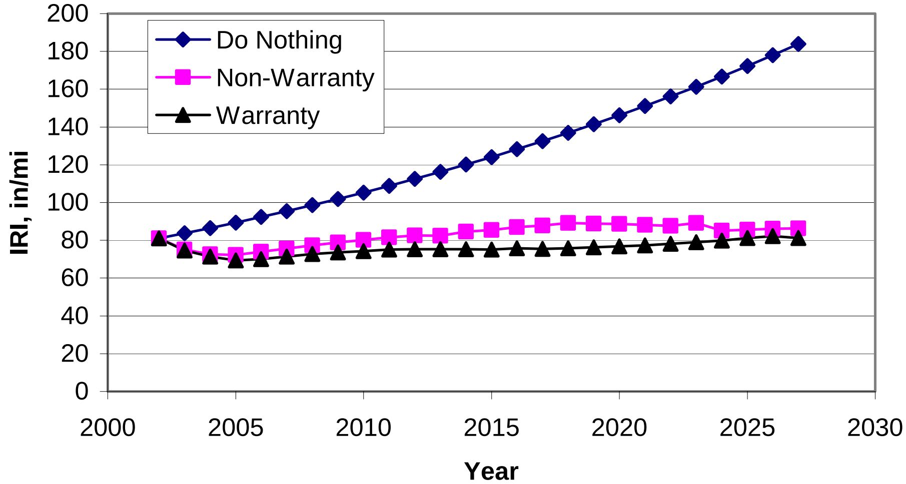

Figure 7: Network Smoothness Under Different Investment Strategies

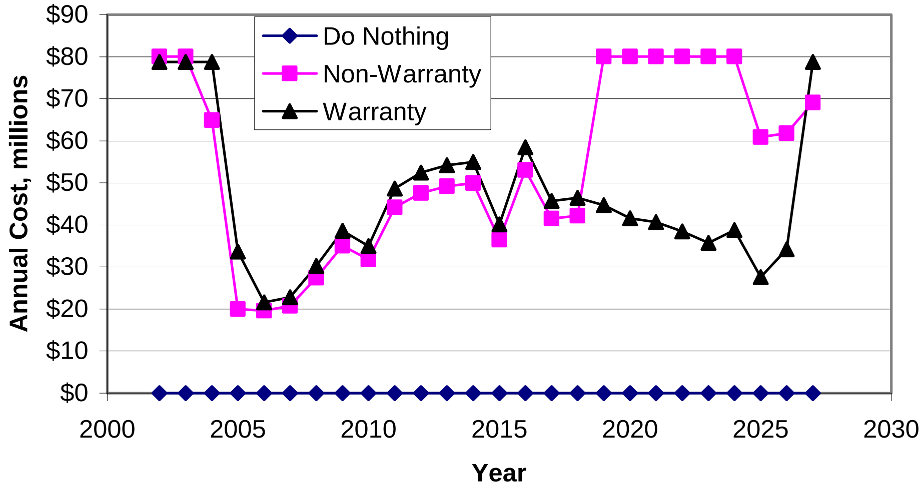

Figure 8: Budget Demand Under Different Investment Strategies.

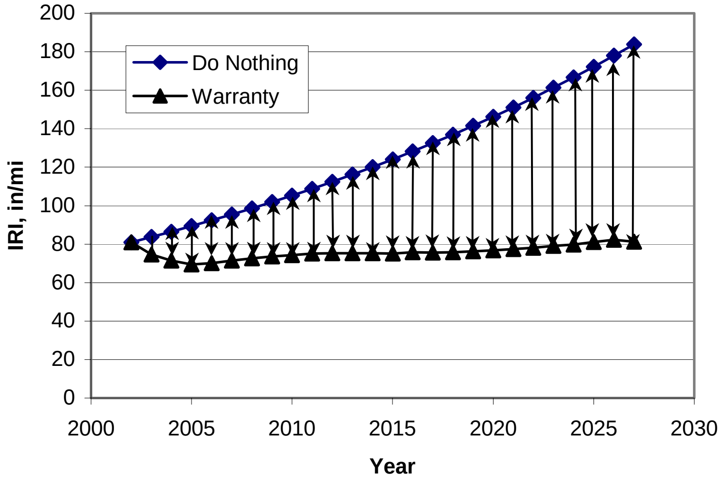

Figure 9: IRI Improvement Created by Capital Investment for Warranty Strategy